FINAL REPORT

Estimated Airborne Releases of Plutonium during the 1969 Fire in Buildings 776-777

Task 2: Verification and Analysis of Source Terms

August 1999

Submitted to the Colorado Department of Public Health and Environment, Disease Control and Environmental Epidemiology Division, Rocky Flats Health Studies in Partial Fulfillment of Contract No. 100APPRCODE 391

"Setting the standard in environmental health"

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SUMMARY

The fire in Buildings 776-777 in May 1969 was a landmark event in the history of the Rocky Flats Plant. In 1957, when the fire in Building 71 was publicly reported, the word plutonium was never mentioned. However, the functions of the Rocky Flats Plant had been revealed before the 1969 fire and the potential impact of the fire was understood by many. Following the fire, a special Investigation Board conducted a detailed analysis of the event. Their report was highly critical of the Atomic Energy Commission and of The Dow Chemical Company (Rocky Flats) for numerous failures to meet fire protection standards. These failures led to an accident whose cost was measured in tens of millions of (~1970) dollars.

Independent scientists also investigated the Rocky Flats environment. Poet and Martell published measurements of plutonium soil contamination that showed releases had occurred during previous years of operation. Their findings led to revelations about the improper storage of plutonium-contaminated oil in the 903 Area. It was also revealed that filter systems had been consumed by fire and that there were no effluent measurements during the 1957 fire in Building 71. Estimates of the releases from the 903 Area and during the 1957 fire are presented in other reports prepared as part of Phase II of the Historic Public Exposures Studies on Rocky Flats.

At 2:27 p.m. in the afternoon of 11 May 1969 (Mother's Day), an alarm from Buildings 776-777 was received at the Rocky Flats fire station. Two minutes later, when the captain and three firemen arrived at the west end of the building, there were flames 18 in. above a glovebox line. At 2:29 p.m., the firemen reported two loud noises and observed fireballs, presumably caused by rapidly burning gases. Using experience gained fighting the 1957 fire, the captain directed that water be used to fight the fire. The fire spread along the north foundry glovebox line, but a metal accountability barrier prevented it from moving into the north machining gloveboxes. It then spread along the north-south conveyer glovebox line, and when fire was observed in that area (2:50 p.m.), a loud noise was heard and vibrations were felt by firemen on the second floor of the building. Between 3:20 and 4:10 p.m., smoke was observed coming from the roof and exhaust vents. The roof was sprayed with water and watched until after 5 p.m. The fire was not considered contained until 6:40 p.m. The fire was considered to be extinguished by 8 p.m., and a fire watch was established at that time. Several small fires recurred during the night and the following morning.

Plutonium metal briquettes were produced from scrap metal in an area adjacent to the production glovebox line and were stored in open cans in a shielded chest in the production area. The plutonium storage glovebox and other gloveboxes contained tons of flammable Benelex and Plexiglas.[a] Benelex, composed of wood fiber and plastic, was used to shield against neutron radiation. Plexiglas was used for shielding and glovebox window material. Combustible oily rags contaminated with plutonium were near the area where the fire started and have been implicated as the root cause of the fire. That fire caused spontaneous combustion of a plutonium briquette that was stored nearby. Heat sensors for the storage cabinet did not function as designed because a large amount of shielding had been added, which effectively disabled them.

[a] Benelex is a trade name of the Masonite Corporation. It is approximately the same density and has the appearance of mahogany. It was used for radiation shielding in Buildings 776-777. Plexiglas is a trade name of Rohm and Haas for several types of clear polymethylmethacrylate. Plexiglas G and Plexiglas SE-3, which is flame retardant, were used for viewing ports in gloveboxes and for shielding when there was a need for visibility through a shielded section.

At the time of the fire, Buildings 776-777 was a large open production area that contained many interconnected gloveboxes, with few fire breaks. There was no installed sprinkler system in the main production area. The glovebox and building ventilation systems provided a continuing supply of oxygen for combustion at the start of the fire. After the fire burned through the gloveboxes oxygen was available from ambient room air.

Relatively little plutonium was released to the atmosphere during the fire. This result is attributed to several factors. First, the captain's decision to use water to fight the fire was a crucial one. In addition, the bravery and persistence of the fire fighters, who made repeated entries into the building, was very important to controlling the fire and limiting the release. A third important factor was that the most important exhaust systems contained multiple sets of nonflammable high-efficiency particulate air (HEPA) filters. The room ventilation air was exhausted through a single set of HEPA filters. However, the booster exhaust and dry air systems each had four to six sets of HEPA filters in sequence to collect airborne plutonium.

Filters in Booster System No. 2 were plugged by smoke during the early stages of the fire, and the main exhaust flow was carried along the Booster System No. 1 exhaust path via the conveyer glovebox line. The booster system exhaust discharged through an inverted-J duct near the surface of the building's roof. Some of the plutonium releases were measured. Booster system sampling was lost due to a power failure at 4 p.m., and the most important releases were not measured. Measurements of surface contamination on the roof indicated that most of the release was via the Booster System No. 1 exhaust duct. Later investigation showed that there was damage to all four stages of HEPA filtration in the Booster System No. 1 exhaust path.

Some outside ground contamination also occurred when fire fighters moved in and out of the building to obtain fresh air supplies. The contaminated area was adjacent to the building on the west and north sides.

The central estimate of the plutonium release to the atmosphere from the fire is ~20 mCi (~300 mg). The 5^{th} to 95^{th} percentile range for the estimate is 10–60 mCi (140–900 mg) of plutonium. This estimate is much larger than measured releases from the main building exhaust, which was sampled throughout the fire. Even smaller amounts were estimated to have been released from the booster and dry air systems before the power outage when those effluent samplers stopped operating. All measured releases amount to less than 3 mg of plutonium.

The estimated distribution of the release to the atmosphere over time is shown in Figure S-1. Most of the release is estimated to have occurred after 4:10 p.m., when dark smoke was discharged by Booster System No. 1. This time history is considered to be quite uncertain but reasonable in view of the events that were reported. Because the wind blew fairly consistently from the northeast throughout the course of the fire, the uncertainty in the release pattern is not a significant factor in estimating transport of the released plutonium to offsite areas.

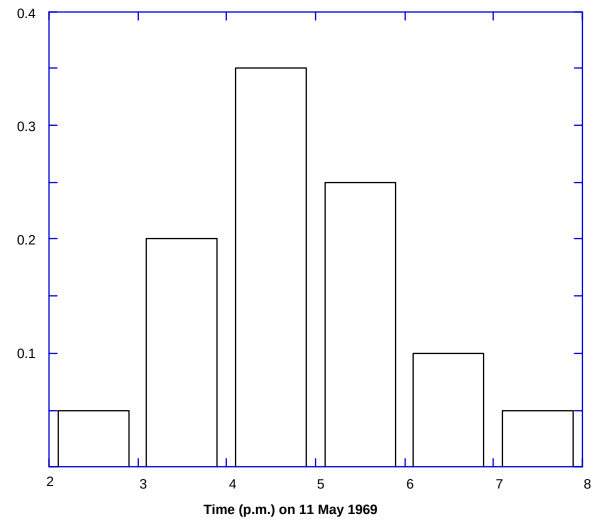

Figure S-1. Estimates of hourly fractions of the plutonium release during the 1969 fire. Most of the release is estimated to have occurred after 4:10 p.m., when dark smoke was observed in the discharge of Booster System No. 1.

The particle size of the released plutonium was not measured. Most of the plutonium release was carried by Booster System No. 1. During part of the fire period, all four stages of HEPA filters in this system were damaged. The fractions of the released material that were comprised of small fire aerosol particles, agglomerated fire aerosol particles, and particles released from the damaged filters are not known. The particles that deposited on the roof were likely larger than those that were not retained, but the original composition of the exhausted material is not known.

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ACRONYMS

AEC	U.S. Atomic Energy Commission
BTU	British Thermal Unit
CCEI	Colorado Committee for Environmental Information
cpm	counts per minute
CWS	chemical warfare system (filter)
DOE	U.S. Department of Energy
FIA	Factory Insurance Association
HASL	(AEC) Health and Safety Laboratory
HEPA	high-efficiency particulate air (filter)

ESTIMATED AIRBORNE RELEASES OF PLUTONIUM DURING THE 1969 FIRE IN BUILDINGS 776-777

1. INTRODUCTION

This investigation is a part of Phase II of the Historical Public Exposures Studies on Rocky Flats performed by *Radiological Assessments Corporation* for the Colorado Department of Public Health and Environment. The Health Advisory Panel for the studies recommended that an independent investigation of the plutonium (Pu)[b] releases from the 1969 fire be conducted as part of Task 2, Verification and Analysis of Source Terms.

The fire in Buildings 776-777 in May 1969 was a landmark event in the history of the Rocky Flats Plant. At the time of the fire in 1957, the word plutonium was never even mentioned and the members of the public had inadequate information to understand the importance of that event. However, by 1969, the functions of the Rocky Flats Plant had been revealed to the public and many individuals understood the potential impact of a fire in a plutonium facility.

The U.S. Atomic Energy Commission (AEC) immediately convened an Investigation Board that took charge of the facility. Their initially classified report, which contains the findings of their detailed analysis of the cause of the fire and their recommendations, was published in August (AEC 1969a). Damage to Buildings 776-777 caused by the 1969 fire was extensive and the Investigation Board's estimate of the cost of facility repair and renovation was very large, ~$50 million.

The Colorado Committee for Environmental Information (CCEI) also undertook an investigation that focused upon environmental contamination around the facility. With support from AEC Headquarters, the CCEI began a program of soil sampling and analysis for locations around the Rocky Flats Plant. The CCEI found and documented the presence of elevated levels of plutonium in soils around the plant. Initial results were provided to the AEC in the fall of 1969 and discussed at a press conference the following February (Martell et al. 1970a). Later that year, the results were published in an article about the 1969 fire (Martell et al. 1970b). At that time, Martell et al. (1970b) believed that the 1969 fire was the cause of the environmental plutonium contamination that they had found.

The CCEI investigation of environmental contamination led to public disclosure of plutonium releases other than the 1969 fire. The leakage of contaminated oil stored in drums in the 903 Area was revealed, although there were no estimates of the amount of plutonium released. Additional information about the 1957 fire was also disclosed, notably that the fire damaged the filtration system and that plutonium was released. Routine effluents from the processing buildings were a third source of plutonium releases that was identified (AEC 1970;

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[b] In this report, the word plutonium, or its symbol (Pu), means weapons grade plutonium, which consists primarily of ^{239}Pu (~93.8%), ^{240}Pu (~5.8%), and ^{241}Pu (~0.36%). Both ^{239}Pu and ^{240}Pu emit alpha particles with average energies of 5.15 MeV and cannot be identified separately by alpha spectrometry. Releases of these two isotopes were the most important sources of radiation exposure that resulted from the 1969 fire. The beta decay of ^{241}Pu forms ^{241}Am, also an alpha-emitter, that can (after about 70 years) account for as much as 18% of the total alpha activity. However, ^{241}Am would contribute little to the doses received by persons exposed during the 1969 fire.

Joshel 1970a). These disclosures were much more explicit and complete than the information regarding the 1957 fire provided in the initial Dow response to the CCEI (Joshel 1969).

To check the CCEI results, the AEC's Health and Safety Laboratory (HASL) also sampled soils in the Rocky Flats area and analyzed them for plutonium and other radionuclides. Krey and Hardy confirmed the presence of plutonium contamination around the plant. The authors also used the data to estimate the locations of plutonium contamination isopleths and to estimate the inventory of plutonium in soil within the area bounded by the 3-mCi km^{-2} contour line (Krey and Hardy 1970). They also initiated a meteorological investigation, conducted by Dickson and Start. The report of that investigation (Dickson and Start 1970) describes the evaluation of the wind patterns during the 1969 fire and the historical record of meteorological data. The report concluded that most of the plutonium soil contamination was not due to the 1969 fire.

Poet and Martell (1972) reported additional measurements of plutonium and americium and the authors' investigations of the timing of the releases that had caused the contamination found east of Rocky Flats. Using measurements of both disturbed and undisturbed areas, they concluded that the contamination could not have come from either the 1957 or 1969 fires and that spilled oil, which contaminated the soil in the barrel storage location (903 Area), was the main source.

Poet and Martell (1972) estimated an environmental inventory more than twice that presented in Krey and Hardy (1970), but noted that additional data were needed for a complete estimate. Krey later performed an analysis of the Rocky Flats component of the plutonium deposition that was based upon differences in isotopic ratios of ^{240}Pu to ^{239}Pu in plutonium from Rocky Flats and from global fallout (Krey 1976). Additional measurements of soil contamination, particularly east of the plant, have been made in recent years. The Phase II Task 4 report (Rope et al. 1999) contains a discussion of the plutonium soil sampling data and other inventory estimates that have been made in recent years.

This brief and necessarily incomplete review of events following the 1969 fire illustrates its importance in opening the door to questions about accidental and routine plutonium releases from Rocky Flats. During Phase II of the Historical Public Exposures Studies, we have also evaluated the magnitudes of the releases from the 903 Area (Weber et al. 1999), reviewed and revised estimates of routine releases (Voillequé 1999a), and made new estimates of releases during the 1957 fire (Voillequé 1999b). Information on uncertainties and bias in effluent sampling, which were developed in the investigation of routine releases, are also used to reassess measured releases from the 1969 fire.

2. INVESTIGATION OF THE 1969 FIRE

On 12 May 1969, R.E. Hollingsworth, General Manager of the AEC, appointed an Investigation Board from various AEC Headquarters organizations to investigate the fire that had occurred on the previous day in Buildings 776-777 at the Rocky Flats Plant. The Investigation Board was at the facility from 13 May to 27 June 1969. It made detailed investigations of the buildings, analyzed physical evidence and relevant records, and obtained testimony from 90 persons. The Investigation Board was assisted by a number of consultants and advisors, including two fire protection experts from the Factory Mutual Research Corporation. Other scientific consultants came from the AEC's Los Alamos and Hanford laboratories. Two special investigators from the Division of Inspection (predecessor of the U.S. Nuclear Regulatory Commission) were also part of the advisory group. Names of the members of the Investigation Board and of their legal counsel, consultants, and advisors are given in Annex E, Volume III of the 5-volume report of the investigation (AEC 1969a).

The Investigation Board took control of the facility to assure that materials were not disturbed and that system configurations would not be changed before their detailed review and analysis of post-fire conditions. Voluminous records were kept of information that was gathered, plans to examine systems, results of measurements, and work to improve building conditions. We carefully examined these records, which were classified, and selected relevant portions that were submitted for classification review. The U.S. Department of Energy (DOE) declassified more than 100 pages of records that were identified in our review. Those records (AEC 1969b) provide information about various aspects of the fire investigation and building rehabilitation activities.

The conclusions of the Investigation Board with regard to origin and spread of the fire are presented in Volume III of the report (AEC 1969a). Although they did not completely rule out sabotage, no basis for concluding that the fire was set intentionally was uncovered. The report states that the most likely cause of the fire was spontaneous combustion of a plutonium briquette[c] that was stored in an open can in a Benelex and Plexiglas[d] storage chest in Glovebox 134-24 in Building 776. Rowland Felt, a plutonium expert, was one of the consultants to the Investigation Board. He made a presentation on fire protection at Rocky Flats in 1996. Ackland, who tape recorded the presentation (Felt 1996) quotes Felt as saying that spontaneous combustion of plutonium-contaminated oily rags was the root cause of the fire and that this caused the briquette to ignite (Ackland 1999).

The glovebox containing the storage chest is located near the west end of the north foundry line. The heat of combustion of the plutonium caused the Benelex and Plexiglas to char and to emit flammable gases that were then ignited. The heat ignited other briquettes and initiated a

[c] Plutonium briquettes are produced by compressing scraps of plutonium metal from rolling, forming, and machining operations. A typical briquette is cylindrical, about 3 in. in diameter, 1 in. thick, and weighs about 1500 g (about 3.3 lb). Even when the scraps have been degreased in a carbon tetrachloride bath, oil may be exuded during compression and some may remain in the briquette that is produced.

[d] Benelex is a trade name of the Masonite Corporation. It is approximately the same density and has the appearance of finished mahogany. It was used for radiation shielding in Building 776-777. Plexiglas is a trade name of Rohm and Haas for several types of clear polymethylmethacrylate. Plexiglas G and Plexiglas SE-3, which is flame retardant, were used for viewing ports in gloveboxes and for shielding when there was a need for visibility through a shielded section.

slow burn of the massive storage chest. Flames later spread to combustible gloves and Plexiglas windows of the glovebox. The initial spread of the fire was along the interior surfaces of the Plexiglas windows in the glovebox system, with air provided by the booster ventilation system.

Initially, smoke from the fire was carried to the exhaust filters of Booster System No. 2 and gradually plugged them. Subsequently, the fire was drawn in an easterly direction by the flow of the glovebox ventilation provided by Booster System No. 1. At the separation point between the north foundry and north machining lines, an accountability barrier blocked further eastward progression of the fire. The fire was then carried along the north-south (N–S) conveyer line and then eastward toward the exhausts of Booster System No. 1. In the early stages, the booster ventilation systems provided air to support combustion inside the gloveboxes. After the fire had breached the confines of the gloveboxes, Plexiglas and Benelex shielding material was burned with oxygen from ambient the room air.

Figure 2.1 is a simple schematic diagram of portions of Buildings 776-777, that focuses on the glovebox lines affected by the fire. The figure is not to scale. The area of the fire was extremely congested. In this schematic, only outlines of the gloveboxes are shown. No attempt had been made to show the many individual work areas. The booster system exhausts are also shown in simplified manner, with only an indication of the direction of flow to the exhaust ducts. (Actually, there are several exhaust points along the line.) The south foundry and machining lines were unaffected by the fire on 11 May and are shown in even less detail.

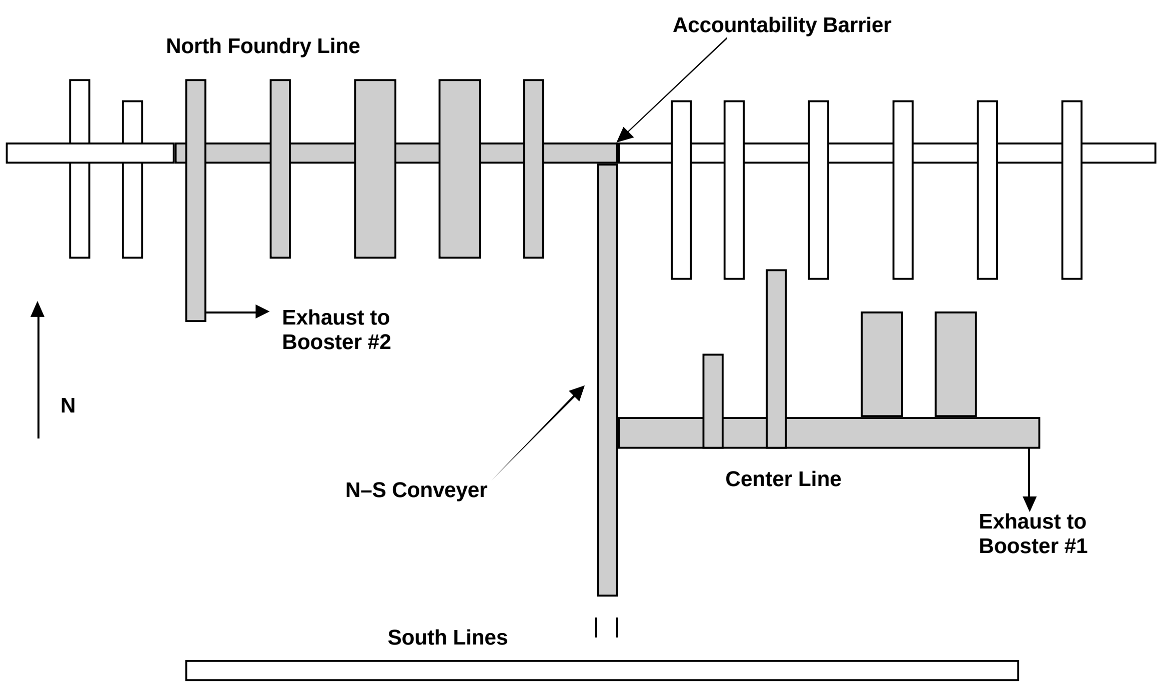

Figure 2.1. Simplified diagram of glovebox lines in Buildings 776-777. Shaded areas were most affected by the fire on 11 May 1969. The drawing is schematic only; it is not to scale and many details are not included. The production area was much more congested than the diagram indicates.

2.1 Fire Alarms

The first alarm from the glovebox heat detection system in Building 776 was received at the Fire Station at 2:27 p.m. on Sunday, 11 May 1969. Six minutes later, the utility operator on the second floor of the building smelled and saw smoke and activated a manual alarm. At 2:34 p.m., a first floor ceiling heat detector caused an alarm. The alarm temperature for such detectors is usually set in the range of 135–165°F (Diliberto 1999). Another alarm, from the fire fighting water supply system in the building, was received at the station at 2:35 p.m. It was probably activated by the first flow of water through the hose reel lines. At 3:15 p.m., an alarm from the combination ceiling and glovebox heat detection system in Building 777 was received at the Fire Station. Before 1969, the wall that originally separated the two buildings had been removed. Heat from the fire was believed to be the source of that alarm. The times quoted are based on the Fire Station clock, which was found to differ from the clock in the Dispatch Office by 2 minutes (AEC 1969a).

2.2 Fighting the Fire

Wayne Jesser was the fire captain on duty with three firemen at the time of the first alarm. Captain Jesser arrived at the west end of Building 776 at 2:29 p.m. After entering the west side of the building, he observed heavy smoke and fire near the location of Glovebox 134-24. At that time, the fire had penetrated the top of the glovebox line and flames about 18 inches high were observed in that area. Captain Jesser directed the other firemen to attack the fire with carbon dioxide (CO_2) and he proceeded further east to use a 50-lb cart-mounted CO_2 extinguisher. He discharged that extinguisher into the glovebox line without effect on the fire. He reported that the fire was moving rapidly to the east in the glovebox line at that time. He returned to the location where the other firemen had used their CO_2 extinguishers, also without effect. At approximately 2:34 p.m., Captain Jesser, who had experience fighting a similar fire involving openly burning Plexiglas in Building 71 in 1957, decided that it was necessary to use water on the fire. Beginning at 2:35 p.m., water was used extensively to fight the fire. There are also reports that magnesium oxide was thrown on isolated areas where plutonium was observed burning, but water spray was the primary means employed.

Because the fire occurred just before the shift change, more personnel were promptly available to fight the fire. All off-duty firemen were called in at 2:43 p.m. and they responded. A total of 33 firemen and security guards made repeated entries into the building to fight the fire. No firefighters from outside the plant staff were involved.

Each fire fighter wore a self-contained breathing air apparatus for protection against airborne plutonium particles in the building. The devices, some of which were borrowed from the Arvada Fire Department, typically provided air for 20 minutes. The need to frequently replenish the air supply meant that the fire fighting activities were somewhat intermittent and probably extended the time required to extinguish the fire.

Because the glovebox lines were shielded with thick layers of Benelex, it was necessary to insert the hoses into the lines or to direct the flow to the ceiling and to bank the water off these surfaces to reach particular locations. There were reports of attempts to move plutonium metal away from fire areas by using the force of the water spray. (Although such efforts would generally be considered inadvisable, there was no evidence that a nuclear criticality occurred during the fire.)

The additional bulk of the breathing air supply system made the work in cramped conditions even more difficult. Nonetheless, with the assistance of other plant staff who filled air bottles, surveyed personnel for contamination, and performed other support work, the fire fighters prevailed.

The investigation report (AEC 1969a) cites the heroism of the fire fighters: "Less than one percent of the total of almost 600 tons of Benelex and Plexiglas shielding was consumed in the fire. Only the heroic efforts of the firefighters limited this burning. Had an appreciable fraction of this shielding burned, there would have been a complete loss of Building 776-777 and its contents and a major release of plutonium to the environment." The firefighters were later formally honored by the AEC (Johnson 1970).

The Investigation Board estimated the energy release of the fire. The total was about 100 million British Thermal Units (BTU). As noted in their citation of the firefighters, this was a small fraction of the amount of energy that was available in the glovebox fabrication and shielding materials. Most of the energy release came from the burning of Plexiglas and Benelex, while oxidation of plutonium contributed only about 5% of the total.

Personnel directly involved in fire fighting activities were surveyed for contamination and were decontaminated by showering and, if necessary, by subsequent scrubbing in the Medical Department. On 11–12 May, 41 persons were decontaminated and counted for internal plutonium contamination. One person was found to have an initial body burden of about 210 nCi. Fecal clearance eliminated most of the plutonium in the first few days after the fire. After that, the long-term lung burden was estimated to be about 22 nCi. In 1969, the maximum permissible lung burden for plutonium was considered to be 16 nCi. Presence of that amount of plutonium in the lung was estimated to produce an annual dose of 15 rem to the lung. None of the other persons counted (numbering 110 by late June) showed appreciable internal contamination. The minimum detectable activity at that time was about 8 nCi.

2.3 Chronology of Events

A detailed chronology of events was compiled by the Investigation Board using personal testimony, the tape of the Autocall fire alarm system recording machine at the Fire Station, and the tape of the plant protection staff's radio transmissions (AEC 1969a, Volume II). A partial listing of the most important events and actions is given in Table 2.1. Elements that were omitted generally refer to locations where the burning was reportedly most vigorous or had intensified. The initial alarm is included; other alarms are listed in Section 2.1.

Table 2.1. Chronology of Events during the 1969 Fire in Buildings 776-777

Time on 11 May 1969	Event or action
2:27 p.m.	First alarm from Bldg. 776-777 was received at the Fire Station
2:29 p.m.	First arrival of firemen at the building
2:30 p.m.	Smoke rapidly filled the building; carbon dioxide extinguishers used without effect
2:34 p.m.	Two explosions heard and two basketball sized fireballs rose to the ceiling
	Initial use of water; smoke rolled out west dock door when it was opened
2:45 p.m.	Fire in gloveboxes 134-126 and 134-128; explosions in that area
2:50 p.m.	15- to 18-in. flames observed along top of north-south (N–S) conveyer line
	These flames moving from north to south; explosion shook second floor

Table 2.1. Chronology of Events during the 1969 Fire in Bldgs. 776-777 (continued)

Time on 11–12 May 1969	Event or action
3:20 p.m.	Main filter plenum checked; smoke on inlet side, no smoke on outlet side
	Fire reported moving into rolling mill in the center glovebox line
	Smoke observed coming from the roof
3:40 p.m.	Fire in a large area described as emitting an orange glow through the smoke
4:00 p.m	Smoke from plant area observed from Denver-Boulder turnpike
	Main filter plenum checked, okay
4:00 p.m.	Roof wetted down
4:10 p.m.	Roof checked and found to be cool
	Smoke coming out of exhaust (on roof)
	Two large billows of smoke from roof rolled over Bldgs. 776-777 and 778, and along the west side of Bldg. 707, toward guard shack (Bldg. 557)
	Fire in center line, N–S conveyor line and press more intense than earlier
4:30 p.m.	Ducts on second floor hot; sprinkler heads on second floor operating
	Booster System No. 2 plenum on second floor checked, okay
4:40 p.m.	Lead shielding dripping off glovebox in north foundry line
	Roof soft in one area
	Fire in ceiling on first floor
5:00 p.m.	Unsuccessful attempt to pry Benelex from N–S conveyor line
5:10 p.m.	Report of a number of small fires on first floor
	Roof okay, hose removed
5:30 p.m.	Fire in N–S conveyor line, more intense going south
5:40 p.m.	Production area still full of smoke
	Fire in ceiling at east end of foundry line, pike pole used
5:45 p.m.	Decision to change room air from recirculating to single-pass mode
5:50 p.m.	Second floor inspected, okay
	Fire still burning in N–S conveyor line, north foundry line, center line
6:00 p.m.	Production area mostly clear of smoke; fires still burning
6:10 p.m.	Pike pole used on ceiling over N–S conveyor line and axe on N–S line
6:20 p.m.	No fire in production area of Building 777
6:20 p.m.	Fires in foundry line, center line, and N–S conveyor line in Bldg. 776
6:30 p.m.	Recurrence of fire in Glovebox 134-24; cans removed from glovebox
6:40 p.m.	Fire in foundry line believed to be under control
6:50 p.m.	Progress on N–S conveyor line fire; small fires in foundry line
7:00 p.m.	Set up patrols through Bldg. 776
7:10 p.m.	Valves in lines for second floor sprinklers turned off
8:00 p.m.	Fire considered to be out
7–12 p.m.	Patrols continued in Bldg. 776; recurrent fires extinguished
12 p.m.–12 a.m.	Patrols continued
8–9 a.m.	Smoldering in Glovebox 134-24 extinguished twice
9:00 a.m.	Fire in Glovebox 134-24 extinguished; cans of plutonium removed
~9:30 a.m.	Fire in briquette storage box in south foundry line found and put out

As is indicated in the chronology and suggested above, the fire was persistent and gained strength on several occasions when the firefighters had to leave the building for new air supplies. There were also numerous flareups or reignitions of the fire, particularly in Glovebox 134-24, where the fire is believed to have started.

The reported explosions were not discussed or explained in the report. Diliberto (1999) has suggested that they may have been due to reactions with carbon tetrachloride (CCl_4) or cutting oil (or both) that were present in the glovebox lines.

2.4 Fire Damage and Loss Estimates

The fire caused extensive physical damage, primarily to areas originally included in Building 776. The portion of the building characterized as the "concentrated damage area" was estimated to cover about 10,000 ft^2. Structural repairs were estimated to cost about $1.6 million. Replacement costs for gloveboxes, conveyors, and shielding in this area were estimated to cost $4.4 million. It was estimated that $2.5 million would be needed for restoration of common services to the individual work areas. These services include power, air, oil, CCl_4, and ventilation system ductwork. Replacement of equipment in the concentrated damage area was estimated to cost $2.8 million. The sum of the estimates for repairs to walls, ceilings, and floors and replacement of support and analytical equipment amounted to $300,000. The estimated total for the concentrated damage area was $11.5 million.

An area of approximately 8000 ft^2 was categorized as the "partial damage area." The largest estimated expenditures for this area, $2.0 million, were for replacement of gloveboxes, conveyors, and shielding. Structural repairs were estimated to cost $1.0 million. Replacement of damaged equipment was estimated to cost $800,000. The total for this area was estimated to be about $3.9 million. In a third damage area, termed the "fringe area," the primary costs were estimated to be due to needed structural repairs ($500,000) and for replacement of analytical and support equipment ($300,000). This size of this area was estimated to be 10,000 ft^2.

Additional costs that were estimated included an addition to Building 707 to accommodate work that could not be performed in Buildings 776-777 as the result of the fire. The addition was estimated to cost $2.5 million. Compartmentalization of Building 776-777 and the addition of a sprinkler system were estimated cost $3.0 million and $600,000, respectively. The total of $6.1 million reflected expenditures that were needed to resume production rather than physical losses due to the fire.

Engineering, design, and inspection costs were estimated at 25% of the identified capital costs, and a contingency factor of 40% was included. The total estimated capital costs were $39.0 million.

The total area in which damage occurred was about 28,000 ft^2, about 28% of the open working area of Buildings 776-777. Plutonium contamination was distributed over a larger area, including some locations outside the building. The cleanup and decontamination effort was estimated to require 600 person-years, and the cost was estimated to be $9.4 million. Thus, the grand total cost estimate for the fire was $48.4 million (AEC 1969a, Appendix K).

The cost estimates given above did not include the cost of plutonium that was lost as a result of the fire or the cost of reprocessing plutonium that was oxidized. Ranges of estimates of irretrievable losses and costs of converting oxides back to metallic form were based upon information available in August 1969. The total cost of plutonium losses and reprocessing was estimated to be about $22 million at that time (AEC 1969a).

A revised estimate of $45 million for repairs was later included in the Serious Accident bulletin that described the fire (AEC 1969c). A retrospective estimate, which may have benefited from the knowledge of actual expenditures (DOE 1980), put the loss at $26.5 million. All of these estimated losses were far in excess of the damage from any of the previous fires or accidents involving plutonium that had occurred at Rocky Flats. The event with the largest loss before the 1969 fire was the fire in Building 71 in 1957. That loss was estimated to be about $800,000 (Epp et al. 1957; Epp 1957; AEC 1969a).

Delays in production of plutonium components for three types of nuclear weapons were also noted in the investigation report. Estimates of costs associated with these delays in weapons production were not included (AEC 1969a).

2.5 Plutonium Handling and Fires at Rocky Flats

The Investigation Board examined the ignition and burning characteristics of plutonium, Rocky Flats plutonium handling experience, and previous plutonium fires at Rocky Flats. The fact that plutonium oxidizes without a flame and does not release flammable combustion products was probably significant in concealing the existence of the fire from personnel who were in the vicinity of Glovebox 134-24 not long before the initial fire alarm was received. This behavior also emphasizes the need for heat sensing equipment to detect such fires. The glovebox ventilation systems were also acting to clear gases released from the Benelex and Plexiglas because of heating. Thus, there could be only very limited build-up of visible combustion products in the glovebox.

Of all the AEC facilities, the Rocky Flats Plant was the one most experienced in the handling and processing of plutonium. Being the most experienced is often associated with having the most experiences. Five of those experiences at Rocky Flats had been notable enough to be the subjects of AEC Serious Accident bulletins (AEC 1955a, 1955b, 1957, 1965, 1966a, 1966b). The post-accident review identified 30 plutonium fires reported to the Fire Department during the 3-year period March 1966–March 1969.

The plutonium forms that were found to constitute the greatest fire hazard were chips or turnings from machining plutonium. Chip fires were considered to be “routine” because they were both common and easy to extinguish. A common method was to drop the burning chip into machining oil to cool it and to deprive the fire of oxygen. Such fires were considered normal occurrences for work with a pyrophoric metal like plutonium and were generally not reported to the Fire Department.

After chips, the forms next most likely to ignite spontaneously were casting skull and briquettes. Casting skull is thin metal and oxide residue that contains impurities and has a porous structure. Both the impurities and the large surface to volume ratio contribute to the probability of spontaneous combustion. The cause of the 1957 fire in Building 71 was considered to be spontaneous combustion of a casting skull stored near Plexiglas in a glovebox.

Strains induced when briquettes are pressed were known to increase the risk of spontaneous combustion. At Rocky Flats, procedures were instituted to reduce this risk and to deal with fires that did occur. Argon purging of the material in the press was used to remove oxygen and avoid spontaneous combustion. If a fire did occur, several measures were in place to deal with it. Special cooled containers were available to hold a burning briquette that could be covered with magnesium oxide sand to prevent access to oxygen. The briquette could also be placed on the steel floor of the glovebox and covered with magnesium oxide sand to smother the fire. To remove heat from the system, CO_2 extinguishers were used to spray and cool the metal glovebox floor (AEC 1969a, Volume II-A).

2.6 Findings of the Investigation Board

The findings and conclusions of the Investigation Board were presented in two parts. The conclusions with respect to the fire were listed in Volume III and those related to management were presented in Volume V (AEC 1969a). Those conclusions and the resulting recommendations are discussed below.

2.6.1 Conclusions about the Fire

Several of the conclusions regarding the cause and spread of the fire have already been mentioned in this report. The Investigation Board found no evidence that the fire was set intentionally. It reported that the fire most likely started when a briquette, stored in an open can in or near Glovebox 134-24, spontaneously ignited and subsequently caused Plexiglas and Benelex in the storage chest to catch fire. The spread of the fire was guided and supported by the air flow of the glovebox ventilation system. The general absence of barriers in the long lines of gloveboxes and within the production area itself allowed the fire to spread without encountering many significant physical impediments.

Because Plexiglas was a significant component of the glovebox system, the Investigation Board concluded that burning of that material and the plutonium would have caused a loss comparable to that suffered. Nevertheless, the Benelex and Plexiglas shielding of the massive storage chest provided a large and immediate source of fuel. Installation of the shielding effectively eliminated the heat sensing system for Glovebox 134-24 and allowed the fire to progress without detection. The presence of the approximately 600 tons of Benelex and Plexiglas shielding made the fire a greater potential threat to building integrity. The Investigation Board also noted that the shielding made it difficult to see all parts of the interior of the glovebox and conveyor lines and increased the likelihood that combustible debris could accumulate there.

Rowland Felt, a consultant to the Investigation Board, later reported that there was evidence of inadequate housekeeping in the area (Felt 1996). When briquettes were formed, oil was often squeezed out of the press and onto the floor of the glovebox. When the metal pieces had not been degreased before pressing, more oil was spilled. Rags used to mop up the oil were reportedly left in the glovebox (Felt 1996). Ackland (1999) quotes Felt as saying that there was evidence that the fire was actually started by spontaneous combustion of a plutonium-contaminated oily rag.

The Investigation Board also concluded that there were no lost time injuries but noted the one significant internal contamination that was previously described in Section 2.2. The Investigation Board also concluded that there was no reason to believe that the fire caused any offsite property damage or injury. The report did not include a thorough analysis of the measurements of releases or an estimate the total plutonium release.

One important conclusion related to both the fire and to management. The Investigation Board stated: "Building 776-777, a vital weapons production facility, did not meet even the minimum AEC fire safety standards. This increased the fire loss and unnecessarily exposed firefighters to fire, plutonium, and nuclear criticality hazards" (AEC 1969a, Volume III).

2.6.2 Conclusions about Management

The Investigation Board faulted both AEC and Dow (Rocky Flats) for failure to evaluate fully the consequences of several decisions that had affected fire safety in Buildings 776-777. First, as noted above, the building was not designed or constructed to meet AEC fire safety standards. The Investigation Board found that not only was no concerted attempt made to achieve the fire safety standards, but several actions were taken that made the building complex even more unsafe. The Investigation Board concluded that the AEC management system failed to assure compliance with existing AEC fire safety policies.

Decisions regarding building modifications and installation of new equipment were made without careful review. Some specific decisions that were directly linked to the 1969 fire were listed explicitly. The expansion of the glovebox system to accommodate new equipment led to overcrowded conditions. The decision, for ease of operations, to store relatively large quantities of plutonium in the glovebox and conveyor lines contributed to worker radiation exposures and a subsequent need for additional shielding. The shielding that was installed was combustible and bulky. It effectively disabled the heat sensors and led to housekeeping problems. The practice of storing plutonium in the glovebox lines also put a large amount of plutonium at risk in the event of an accident.

The Investigation Board noted that Rocky Flats was apparently granted exceptions to established policy. In 1967, the Albuquerque Operations Office had adopted a policy to include sprinkler systems in all new construction, including Building 707 at Rocky Flats. No action was taken to install sprinklers in the production area of Buildings 776-777. (The Board could also have noted that sprinkler installation was a recommendation made in 1957 following the fire in Building 71 [Epp et al. 1957].) Although AEC management had established Manual Chapter 6101, "Administration of the Construction Program," which mandated safety analyses of construction proposals, waivers of some provisions were granted to Rocky Flats. That decision meant that the proposed addition of combustible shielding materials to the lines in Buildings 776-777 did not receive the fire safety review that, in principle, should have occurred.

The Investigation Board also faulted the organization and procedures of AEC and Dow Rocky Flats) that permitted plant modifications without assurance of full safety evaluations. The Albuquerque Operations Office staff did not understand the purpose of the safety analysis procedure and did not implement it at Rocky Flats. The changes to Glovebox 134-24 were cited as an example of a plant modification made without review. No overall evaluation of the effect of changes on safety, particularly fire safety, was made.

The Dow (Rocky Flats) policy was that safety was a line responsibility; however, that concept was not broadly understood to include fire safety. This approach provided opportunities for decisions favoring production goals over safety considerations. The failure to staff a competent centralized safety organization precluded independent reviews and inspections that could have prevented or corrected faulty decisions that contributed significantly to the occurrence and consequences of the 1969 fire. Neither the Albuquerque Operations Office nor AEC Headquarters conducted adequate appraisals of the Dow (Rocky Flats) fire safety organization and procedures (AEC 1969a, Volume V).

2.6.3 Recommendations

To correct the management problems identified above, the Board made a broad recommendation that the structure and operation of the AEC management system for assuring fire safety should be reexamined. The Investigation Board recommended upgrading fire protection requirements at Rocky Flats to assure that facilities not only meet basic standards, but, because of their national security importance and the risks posed by fires in them, that they should achieve a higher standard of fire protection. Minimum improvements needed for Buildings 776-777 to meet a higher standard were identified. These included introducing fire and smoke barriers and automatic sprinklers, with provisions for safe drainage of water used in fire fighting. The Investigation Board recommended that equipment for the safe removal of heat and smoke during a fire be provided and that filters in such ventilation systems be protected. Compliance with National Fire Protection Standard #101, “Safety to Life,” regarding safe exit from hazardous locations within the building was also recommended.

The Investigation Board recommended additional fire protection improvements for Rocky Flats buildings that would provide multiple levels of fire detection and extinguishing capabilities in the glovebox lines and operating areas. These would provide first lines of defense and effectively make the recommended sprinkler system a back-up capability. The ability to isolate a fire area and ventilate it appropriately was also recommended.

It was recommended that reprocessing of plutonium chips, scrap metal, and casting skulls be separated from the manufacturing operations at Rocky Flats. Based on the review of Rocky Flats experience, handling these materials had been identified as the most likely sources of fires because of spontaneous combustion. However, it was noted that for “optimum performance” of specific facilities it might be necessary to make “trade-offs.” To learn more about factors affecting spontaneous combustion of scrap materials, which had been responsible for many fires at Rocky Flats, a research program was recommended.

3. OTHER POST-ACCIDENT INVESTIGATIONS AND REVIEWS

Review and analysis of events that occurred during the 1969 fire led to a number of scientific investigations in the months that followed. Two experimental investigations that relate to particular aspects of the fire are discussed in this section. The first is the study of filters from Booster System No. 2 that were plugged during the early stages of the fire. The post-fire status of other plant filter systems was assessed by in-place physical examinations. The second is testing of mock-up sections of the roof of Building 776. These latter experiments are related to the generation of smoke that was observed and to roof damage. The status of the Building 776 roof itself was also investigated by cutting through and examining several sections of the multi-layered roof surface.

Another important activity that was initiated as a result of the fire was a fire protection survey of the entire Rocky Flats Plant. This survey was completed in early 1970. Because some findings of the survey are related to the results of the fire investigation just discussed (Section 2), this review is discussed first.

3.1 Rocky Flats Fire Protection Survey

After the 1969 fire in Buildings 776-777 and the recognition of inadequacies with regard to fire safety in that building, a fire protection survey of the entire Rocky Flats Plant was conducted by seven representatives of the Factory Insurance Association (FIA). The survey was completed by February of the following year (FIA 1970). Many recommendations for improvements were made as the result of the survey. Some recommendations addressed problems that were common to several locations and others focused on specific buildings. The following discussion considers aspects of the report related to plutonium facilities and to the 1969 fire.

The findings of the fire protection survey support the analysis and conclusions of the fire investigation in several ways. The review of Building 707 refers to its "superior exterior construction, interior module concept, isolation doors on conveyor and glovebox lines, a lower level of combustible shielding, and a high degree of fire protection and detection" in obvious contrast to Buildings 776-777. Nonetheless, there were a number of recommendations for improvement for that new plutonium manufacturing building.

In conclusions regarding Buildings 776-777, the reviewers noted that the building was being decontaminated and that plans for restoration and modification of the building had been developed as the result of other studies. Major improvements, with which the fire protection specialists concurred, were automatic sprinkler protection, installation of isolation doors in glovebox and conveyor lines, reduction of combustible shielding, and plutonium inventory reduction in process lines. However, the fire protection survey team recommended expansion of the sprinkler system beyond the current plans and encouraged the further compartmentalization of the building that was being planned at the time of their review.

An additional bank of high-efficiency particulate air (HEPA) filters was recommended for the main building ventilation exhausts of both Building 771 and Buildings 776-777. It was also recommended that sprinkler protection be provided for these filter banks. One additional bank of HEPA filters, with sprinkler protection, was recommended for each of the other exhausts (the booster and dry air systems) in Buildings 776-777.

In spite of planned improvements, the fire protection survey team noted that other existing deficiencies would continue, in building construction and other areas. Their report (FIA 1970) states "continued use of this building for its present purpose should be limited in duration to only as long as its use is vital to the over-all program." Two major recommendations were related to building construction. Portions of the exterior walls did not have 2-hour fire resistance and needed improvement. They also recommended replacement of the plastic foam insulation on the main building roof with an approved noncombustible material. An alternative approach for the same purpose was to provide a minimum 30-minute fire barrier on the underside of the metal deck. Both of these recommendations relate to the conclusion of the Investigation Board that Building 776-777 did not meet minimum fire safety standards.

3.2 Investigations of the Building 776 Roof

The roof of Building 776 was a matter of some concern during the fire. The chronology (Section 2.3) and discussion in the investigation report both indicate that the status of the roof was investigated after smoke was first observed (3:20 p.m.). The roof was sprayed with water for an unspecified amount of time to cool it, and one location was later reported to be soft (AEC 1969a). The following sections discuss roof structure, damage that was found after the fire, and surficial contamination of the exterior of the roof.

3.2.1 Roof Structure and Damage

The roof was not the type one would associate with a building that housed plutonium forging, machining, and fabrication activities. The design basis for this roof and the decision making procedure used in its selection have not been investigated. At the time of the fire, the roof consisted of a 22-gage ribbed metal decking, coated with a tar-like adhesive, and covered by a 1.5-in. layer of Dow Styrofoam insulation. The Styrofoam was attached to the metal decking with special nails. That layer was covered with a layer of felt, saturated with asphalt and then a 0.5-in. fiber board layer. The fiber board was also nailed, through the lower layers into the decking. The top layer of the roof was a 1/16-in. butyl membrane applied to the hardboard with butyl bonding adhesive (AEC 1969a). At the time of the 1969 fire, there were concrete blocks on top of the roof to hold it in place (AEC 1969a). A photo of the roof taken on 19 May 1969 clearly shows the concrete blocks referenced in the investigation report (Dow 1969, Photo 13628-1).

The roof had been damaged previously. The history of damage and prior repairs to the roof has not been thoroughly investigated; however, photos of the roof (Dow 1964, 1965) show that there had been problems. In June 1964, the roof appeared to have been covered with asphalt and gravel. Cracks in the asphalt were evident. Cutaway sections show a Styrofoam layer but not a fiber board layer above it. Cinder blocks were being used to hold down at least one corner area of the roof. In September 1965, further damage was apparently caused by wind. A temporary cover was blown off large sections and some of the Styrofoam insulation had been lost. The fiber board layer and butyl top cover were installed after that time.

The investigation report notes that the roof was directly exposed to the fire in areas where there was no ceiling above the first floor. Although the ceiling was pulled down in areas where it was burning, the roof sections over the high bay areas were most directly exposed (AEC 1969a). Physical examinations of these areas of the roof were conducted on 19 May 1969. Documentary photos were taken of each layer of the roof in these areas (Dow 1969). Sections of roof (about 1 ft^2) were cut out, and the layers of material on top of the metal base were examined. In the area above the high bay, the upper layers of the roof were intact, but the asphalted felt and Styrofoam layers were clearly damaged by heat from the fire. The Styrofoam layer was blackened and reduced in thickness. Photos of the felt and Styrofoam roof layers in this area were distinctly different from those taken of the same layers in a normal roof area, where there was no damage from the fire (Dow 1969). In the normal area, the Styrofoam layer was distinct and intact. In a roof section exposed to intermediate heat, there was scorched Styrofoam and a gap between layers, but not as much shrinkage of the Styrofoam as was observed in the section above the high bay. Some damage was also exhibited in a fourth area that was examined and photographed.

Photographs of the damaged roof areas show yellow tape labels that indicate plutonium contamination was present in layers penetrated by the nails that held the fiber board in place (Dow 1969; Freiberg 1999). Airborne plutonium had penetrated into the insulation by passing through annular spaces around nails in those areas. The levels indicated ranged from "300" to "3000." Units of disintegrations per minute (dpm) per 100 cm^2 (the standard unit for surface contamination measurements) are presumed, but they are not indicated in the photo. This contamination within the inner layers of the roof is distinct from the contamination of the outer surface of the butyl cover, particularly near the discharge duct for Booster System No. 1, which is discussed in Section 3.2.2.

Laboratory experiments were also performed using sections of simulated roof that were constructed to simulate the Building 776 roof. Preliminary tests had shown that Styrofoam began to melt when the metal reached a temperature of 220°F. When the metal reached 300°F, the Styrofoam layer began to shrink away from the metal surface and at 320°F smoke from the Styrofoam was observed.

When the simulated roof sections were heated, smoke similar to that observed during the fire was produced at a metal pan temperature of about 375°F. Decomposition and melting of the Styrofoam layer was also observed following the heating of test roof sections (Giebel and Rappenecker 1969). In a test when a metal temperature of about 400°F was maintained at the bottom of the metal deck for about 40 minutes, the Styrofoam layer was completely melted but the fiber board was not scorched. In a test when the metal pan temperature reached about 615°F, the fiber board was scorched. Scorching of the fiber board layer was not observed above the high bay following the fire (Dow 1969).

In the experiments, the relevance of relationships between the metal pan temperature and temperatures in layers above the metal is uncertain. Giebel and Rappenecker (1969) reported using a 1.5-in. layer of Styrofoam in their tests. This thickness differs from the 0.75-in. layer identified in the investigation report (AEC 1969a) and by Willging (1969). Comparison of the thickness of the fiber board and the Styrofoam layer in photos of the undamaged roof section (Dow 1969) suggest that the Styrofoam layer was about one inch thick. The laboratory tests were conducted with a Styrofoam layer that was thicker than that present in the roof during the fire. Thus, the temperature of the metal pan of the roof in the high bay areas was not as high as 615°F during the fire because the fiber board was not scorched.

Willging (1969) hypothesized that the light-colored smoke produced by Styrofoam decomposition could move along the underside of the Styrofoam layer because of the presence of ribs in the metal decking beneath the Styrofoam. The ribs are small rectangular air spaces that face upward and extend below the flat surface of the metal pan at intervals across roof sections. The ribs are "open" to the tar-like binder and Styrofoam layers. Thus, decomposing binder and Styrofoam could enter the rib from the top, and smoke that was produced could move along it.

The ribs were aligned along the north-south axis of Building 776-777 (Dow 1964, 1965) and air could flow along them in those directions. The north-south alignment of the ribs is consistent with the observation that smoke was observed to roll from the edge of the roof toward the ground on the south side of the building (Joshel 1970b). The fact that the wind direction was generally from the northeast means that there would be a lower air pressure on the south side of the building than on the north side. Although not mentioned as a factor by Willging (1969) or Joshel (1970b), the wind direction is also consistent with the observed smoke pattern.

The annular spaces around the nails provided a mechanism for plutonium to enter the Styrofoam layer. As noted above, low-level plutonium contamination was found when the roof layers were examined on 19 May. The probability of significant numbers of plutonium particles escaping with the smoke from the decomposing Styrofoam and heated tar-like binder is considered to be quite small.

Parallel roof sections were connected by overlapping a metal lip from each section into the outer rib of the adjoining section. Spaces between the ribs and the support beams were sealed at the edges of the roof to enclose the interior of the building. If heated to a sufficient temperature, the roof sections could be deformed and separate at these joints. The most likely place for this to occur during the fire would have been the high bay areas. The post-fire investigation and the experimental study of the roof indicate that the peak metal pan temperature was probably greater than 375°F but lower than 615°F. At 2:34 p.m., the ceiling heat sensor alarmed at a temperature between 135 and 165°F. The firefighters began to use water spray to fight the fire at 2:35 p.m. The water spray would have suppressed the rate of increase of the temperature of the metal pan in the high bay areas. Thus, the peak temperature may have been substantially lower than 615°F. If any distortion of the roof sections occurred, it would have been in the same area where melting and flow of Styrofoam took place. The melted material and the tar-like binder also present there would act to trap plutonium particles that may have been carried from the interior of the building into the rib spaces. This pathway is not considered to be a significant contributor to the plutonium release during the fire.

Later in 1969, during cleanup and restoration of the building, modifications were made to ductwork that passed through the roof of Buildings 776-777. Afterward, the roof apparently was not sealed adequately in the area of these changes because water leakage was reported in October 1969. Temporary repairs were planned (AEC 1969b). The fire protection survey team (FIA 1970) had recommended replacing plastic foam installation in the roof with an approved noncombustible material, but that action was deferred (AEC 1969b). Later, a second roof was built over the top of the roof that was found to have internal contamination in some areas following the 1969 fire.

3.2.2 Surface Contamination on the Roof

At about 4:10 p.m., dark smoke was seen coming out of the exhaust of Booster System No. 1 on the roof of Buildings 776-777. The dark smoke, typical of burning Plexiglas and rubber, rolled over the roofs of Buildings 776-777 and 778 and continued toward the southwest (AEC 1969a; Joshel 1970b). The booster system exhaust was shaped like an inverted J with the outlet pointed down, and the discharge was directed toward the roof surface.

The plutonium contamination levels on the roof of Buildings 776-777 were measured after the fire. The area on the roof near the exhaust duct of Booster System No. 1 was the most highly contaminated, and the contamination pattern extended to the south and southwest from that area. Figure 3.1 shows the main features of the original surface contamination map (Freiberg 1969, 1999) drawn by Freiberg after the fire. The drawing shows surface contamination levels on the

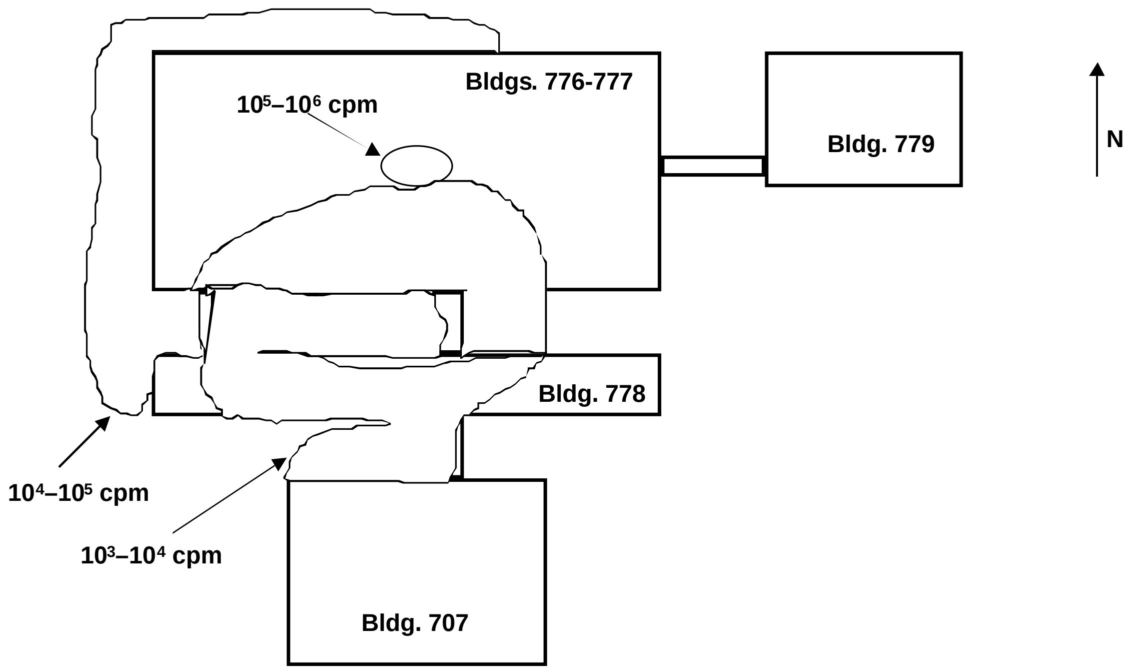

Figure 3.1. Map of surface contamination levels on and near Buildings 776-777 on 12 May. The map is not to scale or in full detail.

building roofs and on the ground. Ground surface contamination was found on the south, west, and north sides of the building. Most ground surface contamination was due to transport of plutonium out of the building on the shoes and clothing of fire fighters when it was necessary for them to obtain new air supplies. The firefighters used the west door for entry to and exit from the building.

The highest levels of contamination were shown to be in the range 10^5–10^6 counts per minute (cpm). For a detector with an area of 67 cm^2 and a counting efficiency of about 30–35%, a count rate of 10^5 cpm corresponds to a surface contamination level of 4–5 x 10^5 dpm per 100 cm^2 (or about 0.2 µCi per 100 cm^2). Considering the areas involved, the total amount of plutonium activity present on the roofs after the fire was estimated to be about 7 mCi, with an estimated range of 3–20 mCi. Approximately 1 mCi (0.3–3 mCi) of plutonium was estimated to be on the ground surface.

A smear survey of the interior surfaces of exhaust lines on the roof of Buildings 776-777 showed that the exhaust from Booster System No. 1 was the most highly contaminated. This is consistent with the contamination survey data for the roof surface. Other locations with comparable levels of interior surface contamination were a toilet exhaust fan vent and vents from the two of the dryers for the glovebox dry air system. Minor contamination of other small ducts, including an office exhaust fan vent, was found (Willging 1969). Releases from these vents are believed to be small because the rooms were located away from the main fire area and flow rates for such exhausts are small. Contributions from these sources are considered unlikely to perturb the broad bounds associated with the measured and estimated releases (see Section 5).

Installation of HEPA filtration for contaminated exhausts to preclude further small releases from resuspension of residual contamination from the interior surfaces was planned for 8–15 August 1969 (AEC 1969b). No record of completion of this action was found.

3.3 Investigation of Burning Characteristics of Materials

Tests on the burning characteristics of Benelex, various types of Plexiglas, and rubber gloves were performed both at Rocky Flats and at the Factory Mutual Research Corporation laboratory. The focus was upon materials that were involved in the fire. Some of the results are given in the fire investigation report (AEC 1969a, Appendix H). The experimental program at Rocky Flats was expanded to consider a broader variety of materials and paints that were or might be used in Rocky Flats plutonium facilities (Beltz et al. 1970).

Plexiglas G was rated easiest to ignite, while the flame retardant type (Plexiglas SE-3) was much more resistant to ignition. The ease of ignition of Benelex shielding material was intermediate between the two types of Plexiglas. All produced flammable vapors when heated to temperatures in the range 250–350°C (482–662°F). The vapors ignited at various temperatures ranging from 340 to 390°C (644 to 734°F). Vapors from the rubber gloves ignited at 325°C (617°F).

3.4 Investigation of Filters in Booster System No. 2

The filters in place at the time of the accident were Astrocel Absolute Air Filters, a type of HEPA filter produced by the American Air Filter Company. Filters used in glovebox locations were typically 8 x 8 x 5-7/8 in. Those used in the booster systems and main filter plenum were 24 x 24 x 11-1/2 in. The filter medium consisted of a combination of asbestos and fiberglass. The specification called for less than 5% organic material in the filter by weight. The filter medium was housed in a fire resistant wooden frame. The fire resistance of the HEPA filter material was very different from that of the combustible paper chemical warfare system (CWS) filters that were in place during the 1957 fire in Building 71. Adhesives used to bind the filter medium to the holder and to seal the filter were similar to those used in CWS filters (Burchsted and Fuller 1970).

Cichorz et al. (1969) examined a number of filters using infrared spectroscopy, x-ray diffraction, emission and mass spectrometry, and other advanced analytical techniques to determine the nature of residual materials present in the filters. Filters that had not been used were analyzed to define a reference point. One of the filters analyzed had been used for 18 months in the first stage of the Booster System No. 2 filter plenum and was removed in a filter change that occurred in late March, 1969. That filter was called the pre-fire filter. Two filters removed after the fire from the first stage of Booster System No. 2 were analyzed. These were called the post-fire filters. Also analyzed were an intact glovebox filter removed from the north foundry conveyor and a glovebox filter that was exposed to a simulated fire.

The pre-fire and post-fire filters taken from the booster system contained large amounts of medium to heavy weight petroleum oil, or a mixture of oils, not found in unused filters. The oil content of the post-fire filters was 50–100% of that in the pre-fire filter. Because the pre-fire filter had been used for 18 months before removal and the post-fire filters had been in place for only 1.5 months, the investigators concluded that the buildup of oil had been accelerated during the fire (Cichorz et al. 1969).

Elevated amounts of ammonium chloride and lead were found in post-fire filters. There were several obvious sources of the lead (shielding material, lead-lined gloves, and leaded glass) but a specific source of ammonia was not found. Combustion products (CO_2, elemental carbon [e.g., soot], and HCl) from the burning of Plexiglas and Benelex were found in the post-fire filters. The same combustion products were found in the conveyor glovebox filter, although the hydrocarbon distribution was different. It was hypothesized that hydrocarbons from the rubber gloves may have volatilized (Cichorz et al. 1969).

Materials for the simulated fire consisted of Benelex, Plexiglas (G and SE 3), lead-lined rubber glove, magnesium chips, and paper tissues saturated with CCl_4. The principal purpose of the fire simulation was to determine if these materials would produce the ammonium chloride and petroleum oils that were observed in the post-fire filters. Those materials were not found in the filter exposed to the simulated fire. Other combustion products found in filters exposed during the actual fire were present in the filter exposed to the simulated fire (Cichorz et al. 1969).

The oils that were found, although partially oxidized, were similar to oils used in the production lines in Buildings 776-777. The presence of large amounts of oil was cited as a concern in the fire protection survey report (FIA 1970).

3.5 Investigation of Damage to Filters in Booster System No. 1

The observation of dark smoke discharged from Booster System No. 1 and the contamination on the roof around the inverted J duct are both indications that these filters were damaged. The damage was confirmed when the filters were inspected on 27 May (AEC 1969b).

The exhaust from this system passed through four stages of HEPA filters. Filter frames in the first stage were charred by the heat. One filter had disintegrated and the layers of filter media were disheveled. There was also some shrinkage of filter media, but the supporting framework appeared to be undamaged. The supporting framework for the other stages was also found in good condition. One of the filters in the second bank had disintegrated. Most of the filter media had fallen to the floor, but the wood frame was still in place. Other filters in the second bank were blackened. Similar blackening was observed in the third stage, but no filters were out of place. In the fourth stage, the downstream faces of the lower layers of filters were still white. The painted framework was not blistered except at the top of the filter plenum. There was some charring of filter frames in the top row and the top of the plenum was blackened, both indicating higher temperatures in that area. The top row of filters "looked rather bad," but the filters were still in place (AEC 1969b). From the description of the filter systems, it seems clear that portions of all four stages of filters were damaged before the fire was extinguished.

The HEPA filter material was fire resistant; however, exposure to high temperatures would damage the adhesive sealants used in filter assemblies (Burchsted and Fuller 1970). The observations of greater damage to filters in top rows of the four filter banks is consistent with this mechanism of failure.

Willging (1969) suggested the possibility of ignition of flammable vapors downstream of the filter system, which would lead to release of uncontaminated smoke. No explicit evidence for such an event was identified. The studies of Booster System No. 2 (see Section 3.4) did not reveal flammable decomposition products in the filters. That finding is not supportive of burning downstream of a damaged filter. Petroleum oils were found on the filters taken from Booster System No. 2. It is likely that similar oils were carried to Booster System No. 1 as well. Even though there was damage to them, the first three banks of filters would probably have collected any oil carried in that system. Thus, there seems to be no mechanism that would support the conjecture of uncontaminated smoke from Booster System No. 1.

All of the fourth stage HEPA filters and the top row of filters in the third stage of HEPA filters for Booster System No. 1 had been replaced by 9 June 1969 (AEC 1969b). Although plans for rehabilitation of the entire filtration system and the addition of improved fire protection were made (AEC 1969b), the date when this was completed was not found.

4. AMOUNT OF PLUTONIUM INVOLVED IN THE FIRE

The amount of plutonium involved in the 1969 fire has been estimated in several ways, each of which is uncertain. All of the estimated amounts are relatively large. Felt (1996) indicated that, in some areas, 16-kg ingots of plutonium metal could be separated by 18 in. A simple calculation shows that, with that spacing, more than 1,000 kg of plutonium metal could be present in a 100-foot foundry conveyor line.

Fairfield and Woods (1978) estimated that roughly 1 ton of plutonium was oxidized. The calculation was based on information in the investigation report (AEC 1969a). The total energy release during the fire was “on the order of 100 million BTU.” The heat released from oxidation of plutonium metal is 5.2 BTU per gram. The fraction of the energy release due to oxidation of plutonium is stated to be “less than 5 percent” and “about 5%” in different sections of the document. Assuming a heat release of 100 million BTU and that exactly 5% of the energy was due to plutonium oxidation leads to the estimate of about 960 kg (2100 lb) of plutonium oxidized.

The investigation report indicated that the amount of plutonium involved was quite uncertain in August 1969 (AEC 1969a). Years later, Barrick (1981) stated that a few hundred kilograms of plutonium was damaged or completely oxidized and required reprocessing. He indicated that a larger amount was undamaged. This statement, which was intentionally vague, could have been based on knowledge of the actual amounts of plutonium that were later reprocessed.

Ackland (1999) states that about 7,600 lb (about 3,500 kg) of plutonium was in Buildings 776-777 at the time of the fire and that less than 10% was damaged or oxidized. He cites the report of the Investigation Board (AEC 1969a) as the source of this information.

In any event, the amount of plutonium involved in the 1969 fire greatly exceeded that involved in the 1957 fire in Building 71. If 400 kg of plutonium were oxidized in the 1969 fire, that would be nearly 20 times the amount directly involved in the 1957 fire (Voillequé 1999b).

5. MEASURED AND ESTIMATED RELEASES OF PLUTONIUM TO THE ATMOSPHERE

Exhausts from the main building filter plenum and from the booster systems were routinely sampled as part of normal operations. Those samplers were in operation at the time the 1969 fire began. Samples were collected and analyzed using the standard methods employed at Rocky Flats. Voillequé (1999a) describes the methods used and the analysis of biases and uncertainties associated with the measurement techniques.

The following subsections discuss results of effluent measurements, estimates of unmeasured releases, and the question of particle size of the aerosol released.

5.1 Measurements of Releases

At the time the fire began, samplers were operating to measure releases from the main stack, the two booster systems, and the glovebox dry air system. The status of all systems was verified at 8 p.m. The four main exhaust fans were operating at medium speed. Booster System No. 1 was also operating in a normal way. The three exhaust fans for Booster System No. 2 were all operating but little air was passing through the filters because they were plugged. The glovebox dry air system was off at that time. A record from a pressure sensor suggests that system may have failed between 2:45 p.m. and 3:00 p.m. Power to that system was definitely lost at 4 p.m. when a truck struck a utility pole outside the building (AEC 1969a; Felt 1996).

As the result of the 4 p.m. accident, electrical power to the samplers for the booster systems and the dry air system was also lost. The sampling system for Booster System No. 1 lost power before the time that the black smoke was reported to have been discharged from that exhaust (4:10 p.m.). The samplers for the main building exhaust were not affected by the accident and continued to operate.

The filters used to collect effluent samplers had been changed on Friday, 9 May. Although filters were changed daily during the week, it was typical to not change filters during a weekend (see Voillequé 1999a). The samplers for the booster systems and the dry air system operated for about 48 hours before the power failure. The filters for the main exhaust plenum were not changed until 14–15 May. One filter was changed on 14 May after about 120 hours of operation. The other two filters were changed on 15 May after about 144 hours of operation (AEC 1969a; Joshel 1969). Table 5.1 shows the plutonium concentrations measured in the filters that were collected from the effluent samplers.

The Investigation Board reported only the concentrations shown in Table 5.1 and did not make an estimate of the amount of plutonium released to the atmosphere. The data do not appear to have been reviewed critically. In particular, the fact that all of the releases were not measured seems to have been ignored. This approach may have been influenced by the fact that environmental measurements did not show the presence of significant quantities of plutonium. The sheer magnitude of the fire protection problems that were revealed during investigation of the fire clearly received much more attention from the Investigation Board and their advisors.

Table 5.1. Measured Plutonium Concentrations in Exhaust Ducts, 1969 Fire

Exhaust location	Approximate duration (hours)	Average plutonium concentration (pCi m^{-3})
Booster System No. 1	48	3.4
Booster System No. 2	48	6.6
Glovebox Dry Air System	48	6.3
Main building exhaust		
Sampler 1	120	1.4
Sampler 2	144	9.8
Sampler 3	144	16
Time-weighted average		9.5

The exhaust flow rates for the four systems are listed in Table 5.2. The main plenum exhaust rate reported by Joshel (1969) appears to have been incorrect. It was about half the flow rate shown in the table. Table 5.2 also contains estimated releases for the periods during which measurements of effluent concentrations were made. The estimated release for Booster System No. 1 is known to be too low because the system continued to operate after the sampler stopped. Estimates for Booster System No. 2 and the Glovebox Dry Air System are uncertain because their effective operating histories are not known. Neither the time at which the booster filters were plugged nor the time of shutdown of the dry air system is known with confidence. Corrections for bias and uncertainty estimation for the main exhaust sample can be based upon the results for routine effluent sampling in large ducts (Voillequé 1999a). The largest measured release was that from the main building exhaust. The central estimate was 440 µCi, with a 5^{th} to 95^{th} percentile range of 180–2600 µCi.

Table 5.2. Exhaust Flow Rates and Estimates of Measured Releases, 1969 Fire

Exhaust location	Approximate exhaust flow rate (ft^3 min^{-1})	Estimated plutonium release (µCi)[a]
Booster System No. 1	12,000	3.4[b]
Booster System No. 2	6,000	3.2[c]
Glovebox Dry Air System	15,000	7.9[c]
Main building exhaust	190,000	440[d]

[a] Release estimates for periods when samplers were operating; see Table 2.1.

[b] Estimate is known to be too low because system continued to operate after sampler power was lost.

[c] Estimates are uncertain because the duration of effective operation of the exhaust system is not known. Filters in Booster System No. 2 were plugged by smoke and oil mist (flow history unknown) and Glovebox Dry Air System may have failed before power to sampler was lost.

[d] See Voillequé (1999a) for a discussion of the bias and uncertainty for release estimates based on sampling of a few points in a large duct.

All of the release points, including the main building exhaust, discharged near roof level on top of Buildings 776-777. The fact that the smoke observed by persons nearby was described as rolling off the roof is consistent with the location of the release points. There was a report of smoke having been observed from the Boulder Turnpike at 4 p.m., suggesting an elevated plume. This observation appears to be inconsistent with the reports of persons on the scene. A possible explanation may be evaporation of water that had been sprayed on the roof to cool it. The tests made of the effect of heat on the roof suggest that the heating from inside the building would not have been sufficient to evaporate the cooling water (Giebel and Rappenecker 1969). Diliberto (1999) has suggested that the material observed from the highway may have been the water spray that was being applied to wet and cool the surface of the roof.

5.2 Estimates of Unmeasured Releases

Physical evidence, in the form of plutonium surface contamination, indicates that Booster System No. 1 was the principal source of releases to the environment during the 1969 fire. Releases from Booster System No. 1 continued after effluent sampling was interrupted. The method used to estimate the unmonitored releases from this source is described in this section.

As noted earlier, the exhaust duct for the exhaust from Booster System No. 1 was shaped like an inverted J. The opening of the duct was directed toward the roof surface, and plutonium contamination was found beneath the discharge. The contamination was also spread to the south of the Booster System No. 1 discharge point, consistent with the light winds that blew from the northeast during the period of interest. The spread of contamination indicates that there was not complete retention of the material exhausted from the booster system duct.

The fraction of the activity that was retained on the roof is quite uncertain. Because it was a warm day, asphalt used to repair the butyl cover of the roof may have been somewhat sticky and could have been an efficient collector of particles. Photos of the roof (Dow 1969) show that such repairs had been made. The locations of the repaired areas are not all known because photographic coverage of the roof surface is incomplete.

Measurements of the efficiency of gummed-film, which is a sticky paper collector used to collect fallout particles, indicate relatively low collection efficiencies (Beck et al. 1990). Collection efficiencies between 20 and 30% were found for conditions when very little rain occurred. These results are not directly applicable to deposition on the roof, but they may be indicative. In this assessment, we considered that the fraction of discharged particles retained on the roof could vary over a broad range, from 0.05 to 0.75. The absence of information (see Section 5.3) about the sizes of particles released from the duct is an important contributor to the uncertainty.

Estimates of the fraction of the plutonium that was retained by the roof and of the amount of plutonium that was found on the roof can be used to estimate the amount that escaped into the atmosphere. The total discharge from the duct can be estimated by the ratio of the amount on the roof to the fraction retained by it. The amount carried away in the wind is then estimated as the difference between the total discharge and the amount that was found on the roof.

The amount of plutonium that was deposited on the roof was estimated to be 7 mCi, with a range of 3–20 mCi (see Section 3.2.2). The amount on the ground, also discussed in that section, is considered to be due primarily to firefighters tracking plutonium out of the building and not related to the release from Booster System No. 1. In the calculations, the amount of plutonium retained by the roof is represented by a log-triangular distribution with bounds of 3 and 20 mCi and a mode of 6 mCi. This distribution returns an average value of about 7 mCi, the central estimate from Section 3.2.2.

The fraction of the plutonium that was retained by the roof was represented by a truncated lognormal distribution. While lognormal distributions are frequently encountered in observations of environmental parameters, truncation is necessary in this case to avoid selecting values of the retention fraction that are mathematically impossible. We developed a distribution of estimates that is approximately lognormal in the central portion (0.15–0.6), with declining probability outside that range to the bounding values used. This distribution was chosen to cover the broad range of values (0.05–0.75) and still return a mean (0.3) that is consistent with the observations of particle retention by gummed-film. Figure 5.1 shows the retention fraction distribution that was used to estimate unmeasured releases.

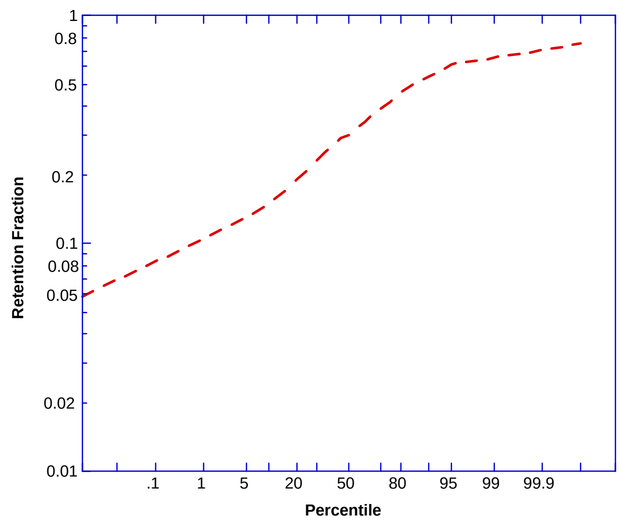

Figure 5.1. Distribution of retention fractions used to estimate unmeasured releases.

Results of calculations indicate that the unmeasured release of plutonium from Booster System No. 1 was likely more important than releases that were measured (central value of about 0.4 mCi). The central estimate of the unmeasured release from the booster system is ~20 mCi or 0.3 g. The spread of estimates of the unmeasured release is large, with 5^{th} and 95^{th} percentile values of about 10 mCi and about 60 mCi, respectively. The corresponding range of masses of plutonium is ~0.14 g to ~0.9 g.

The estimates of the amount of the unmeasured release are relatively insensitive to the choice of distributions for the amount of material on the roof or the fraction retained by the roof. Use of a uniform distribution over the range 0.05–0.75 for the fraction retained would decrease the central release estimate to about 11 mCi. Use of that distribution would also broaden the range (5^{th}–95^{th} percentiles) of release estimates to 2–80 mCi.

It is estimated that some of the release occurred during the early part of the fire but that most of the release occurred after 4:10 p.m., when billows of black smoke were observed coming from the booster exhaust. Figure 5.2 shows the estimated distribution of the release over time. Three-fourths of the total release is estimated to have occurred after 4 p.m. Most of that fraction (and 60% of the total) is assigned to the period between 4 and 6 p.m. Because the wind direction was fairly consistent during the fire, the uncertainty in the time history of releases is not likely to have a large effect upon estimates of the areas to which the plume was carried.

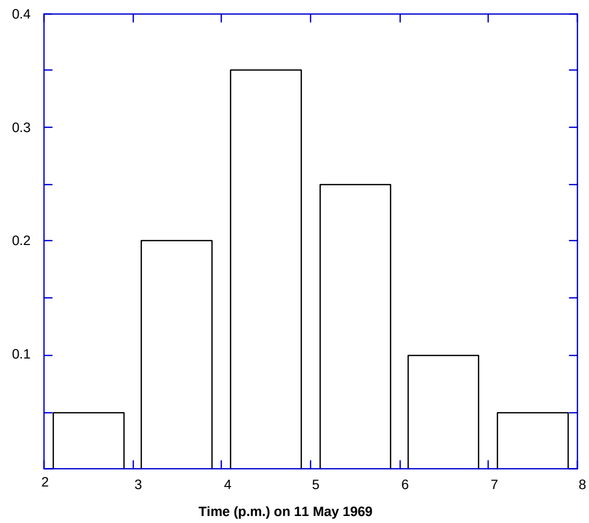

Figure 5.2. Estimates of hourly fractions of the plutonium release during the 1969 fire. Most of the release is estimated to have occurred after 4:10 p.m. when dark smoke was observed in the discharge of Booster System No. 1.

The 1969 fire created a great potential for release of plutonium to the atmosphere and for contamination of nearby areas. Several factors kept that potential from being realized. The actions of the fire fighters, including the important decision to use water on the fire, were crucial. The persistence and bravery of these men has been justly noted and commended. Had they not prevailed in the battle to maintain the structural integrity of the building, the result would have been quite different. The building filtration systems were also quite important in limiting the release. The three systems that were most challenged each had four to six stages of HEPA filters that were nonflammable. The heat did eventually damage all four stages of the filters for Booster System No. 1, but the improvements in filter systems that occurred after 1957 were very important in limiting the consequences of the 1969 fire.

5.3 Particle Size of Released Plutonium

No measurements of plutonium particle size were made for the effluents from the 1969 fire. Some discharges resulted from penetration of particles through normally operating HEPA filter banks. Measurements at Rocky Flats documented in Hayden (1976) indicate that such particles are small, with activity median aerodynamic diameter of about 0.3 µm. Some Rocky Flats fire aerosol measurements also showed that the particles produced were small (Mann and Kirchner 1967). However, the data of Anderson (1964) suggest that high relative humidity due to application of water to the fire could have caused agglomeration, leading to an aerosol with a larger activity median aerodynamic diameter.

Most of the plutonium release was carried by Booster System No. 1. During part of the fire period, all four stages of HEPA filters in this system were damaged. The fractions of the released material that were composed of fire aerosol particles, agglomerated fire aerosol particles, and particles released from the damaged filters are not known. The particles that deposited on the roof were likely larger than those that were not retained, but the original composition of the exhausted material is not known.

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